

**United States Patent** [19]

Bluck et al.

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[54] **PROCESS FOR THE MANUFACTURE OF SEAMLESS METAL-CLAD FIBER-REINFORCED ORGANIC MATRIX COMPOSITE STRUCTURES**

[75] Inventors: Raymond M. Bluck, San Jose, Calif.; Harold G. Bush, Yorktown, Va.; Robert R. Johnson, Saratoga, Calif.

[73] Assignee: The United States of America as represented by the Administrator of the National Aeronautics and Space Administration, Washington, D.C.

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**Related U.S. Application Data**

[62] Division of Ser. No. 921,572, Oct. 21, 1986, Pat. No. 4,923,761.

[51] Int. Cl.<sup>5</sup> ..... B29C 45/14

[52] U.S. Cl. .... 264/257; 264/261; 156/625; 156/634; 156/172; 156/187

[58] Field of Search ..... 264/257, 258, 261; 156/625, 634, 172, 187

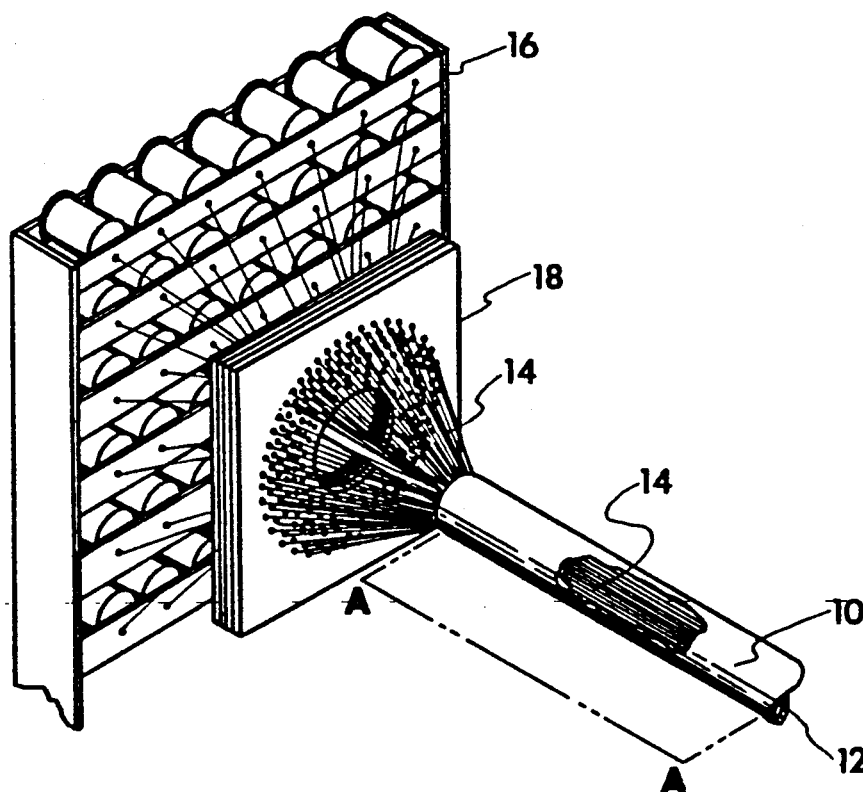
Primary Examiner—Jay H. Woo

Assistant Examiner—Jeremiah F. Durkin, II  
Attorney, Agent, or Firm—George F. Helfrich

**[57] ABSTRACT**

A process for producing seamless metal-clad composite structures includes providing a hollow, metallic inner member and an outer sleeve to surround the inner member and define an inner space therebetween. A plurality of continuous reinforcing fibers is attached to the distal end of the outside diameter of the inner member, and the inner member is then introduced, distal end first, into one end of the outer sleeve. The inner member is then moved, distal end first, into the outer sleeve until the inner member is completely enveloped by the outer sleeve. A liquid matrix material is then injected into the space containing the reinforcing fibers between the inner member and the outer sleeve. Next a pressurized heat transfer medium is passed through the inner member to cure the liquid matrix material. Finally, the wall thicknesses of both the inner member and the outer sleeve are reduced to desired dimensions by chemical etching, which adjusts the thermal expansion coefficient of the metal-clad composite structure to a desired value.

3 Claims, 3 Drawing Sheets



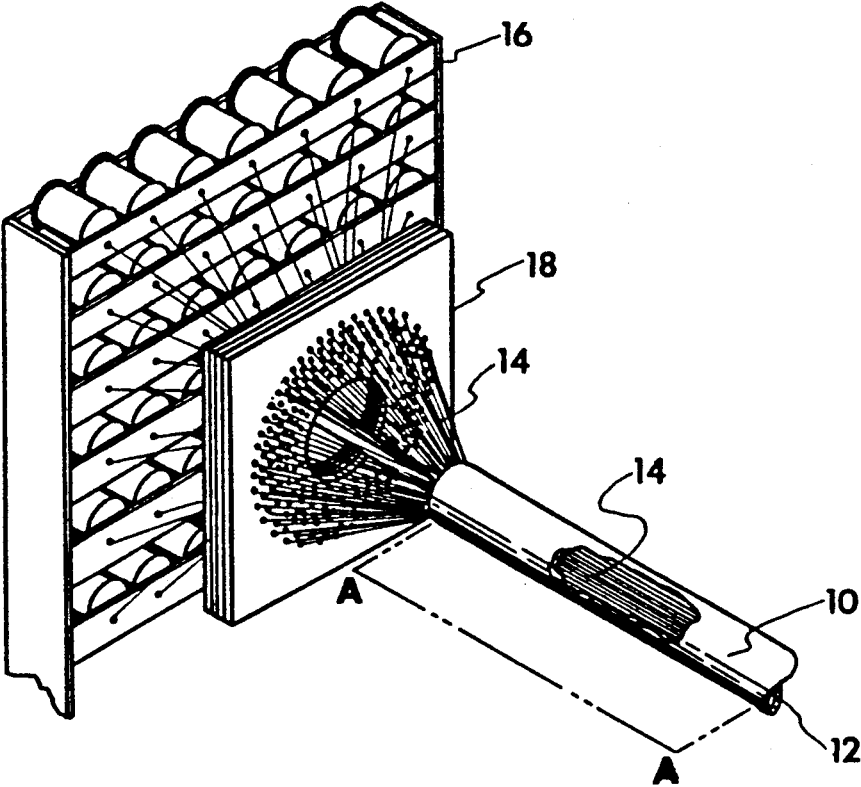


FIG. 1

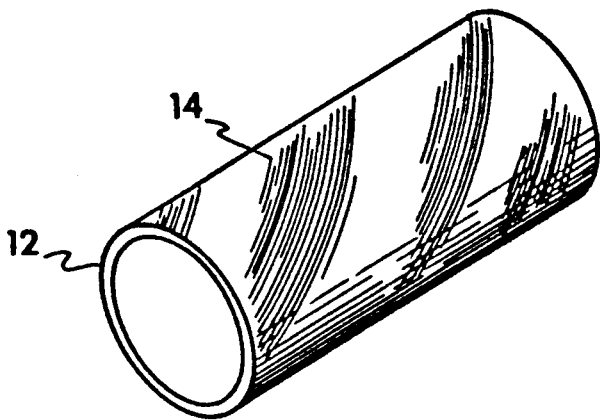


FIG. 2

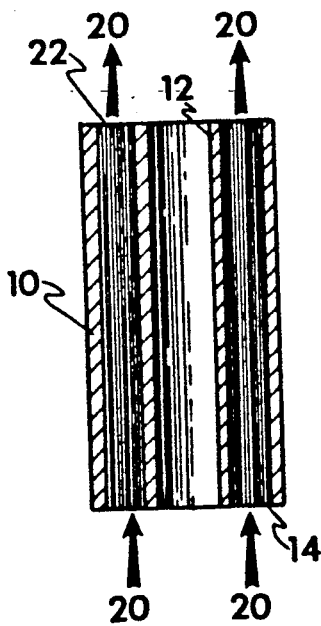


FIG. 3

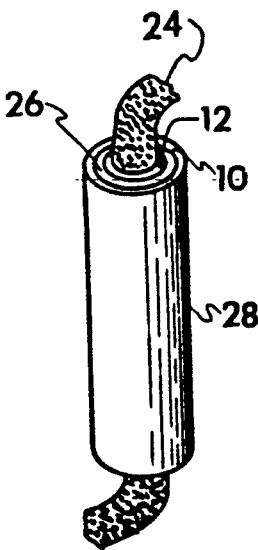


FIG. 4

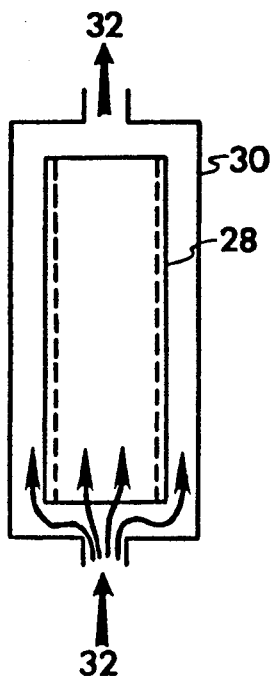


FIG. 5

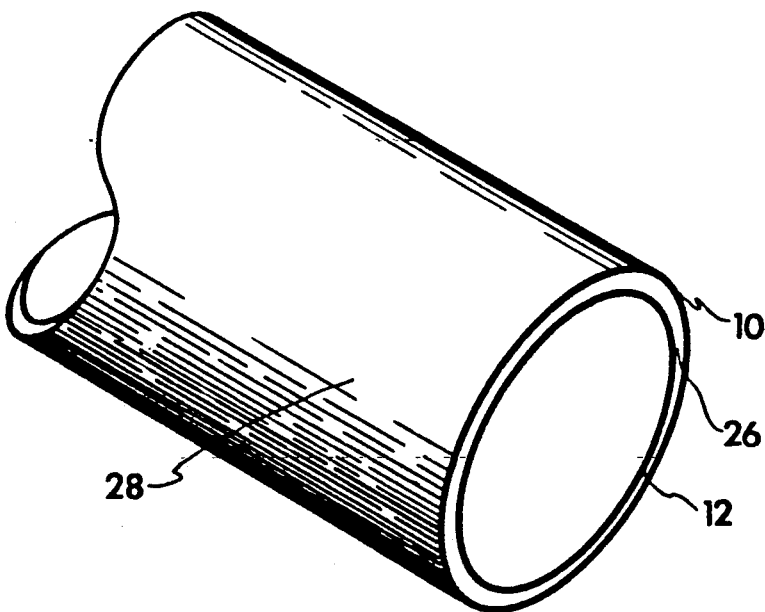


FIG. 6

## PROCESS FOR THE MANUFACTURE OF SEAMLESS METAL-CLAD FIBER-REINFORCED ORGANIC MATRIX COMPOSITE STRUCTURES

This is a division of application Ser. No. 06/921,572, filed Oct. 21, 1986, which is now U.S. Pat. No. 4,923,751.

### ORIGIN OF THE INVENTION

The invention described herein was made in the performance of work under a NASA Contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435, 42 U.S.C. 2457).

### BACKGROUND OF THE INVENTION

This invention relates to composite material articles and processes for their manufacture, and more particularly to seamless metal-clad filament-reinforced resin matrix composite tubular structures and processes for their manufacture.

Composite materials have great potential for solving challenging and often critical problems in the design of spacecraft and space structures. Mission objectives often impose severe requirements for dimensional stability over a wide range of temperatures, minimum weight, low cost, high stiffness and strength, thermal and electric conductivity and, more recently, the capability to withstand laser and nuclear threats. Probably the greatest constraint upon long orbital life for spacecraft is the susceptibility to attack by atomic oxygen in low earth orbit.

Composite materials offer specific strength, specific rigidity, and thermal expansion characteristics that are superior to metallic materials; however, possessing strength and other properties in one primary direction, they lack transverse properties including torsion. Furthermore, conventional graphite-epoxy orientation mix constructions suffer from deleterious hygroscopic effects, such as moisture absorption and desorption, which effect dimensional change. A related serious problem is outgassing of condensable organic constituents, which will condense and deposit on critical surfaces in a space environment. In addition, a process must be provided for shielding ultraviolet radiation to protect the organic matrix from deleterious exposure, and for providing electrical conductivity to preclude static charging in space.

Metal-clad composites make a significant advancement over those composite systems being used for both spacecraft and aircraft; however, the material consolidation and tooling advances necessary to realize the potential of such metal-clad composites have not hitherto been achieved. Prior methods have involved tape-wrapping a metal foil, or spraying or depositing a thin metallic film on the fiber reinforced composite structure surfaces. Such methods suffer from lack of adhesion between the metal surface and the composite, porosity of surface, and high cost; and these methods have resulted in a product which is difficult to join to other structures and is non-tunable to precise thermal dimensional stability after manufacturing.

Accordingly, it is an object of this invention to provide an efficient method of producing seamless metal-clad composite structures.

A further object of this invention is to improve circumferential heat transfer in seamless metal-clad com-

posite structures to reduce thermal stress to acceptable levels for the space environment, and to reduce thermal distortion of the structures due to circumferential temperature gradients.

5 A further object of this invention is to shield the organic matrix of a metal-clad composite structure from deleterious exposure due to ultra-violet radiation and to provide electrical conductivity to preclude static charging.

10 A further object of this invention is to provide a method of sealing and isolating the organic matrix of a metal-clad composite structure to preclude vaporization of condensable solids which will coat optical sensor and optical reflective surfaces.

15 A further object of this invention is to provide a method of toughening composite laminates of a metal-clad composite structure against mechanical impact damage.

20 A further object of this invention is to provide a method of hardening exposed surfaces of a metal-clad composite structure against directional radiant heating, such as laser, by providing transverse circumferential heat transport.

25 A further object of this invention is to provide a highly conductive surface of a metal-clad composite structure to dissipate or inhibit electron emission through a boundary.

30 A further object of this invention is to provide protection to the organic matrix of a metal-clad composite structure against deleterious attack by atomic oxygen.

Other objects and advantages of this invention will become apparent hereinafter in the specification and drawings which follow.

### SUMMARY OF THE INVENTION

According to the present invention, the foregoing and additional objects are attained by providing a metallic outer sleeve which is capable of enveloping a hollow metallic inner member having continuous reinforcing fibers attached to the distal end thereof. These fibers may be collimated or pre-wrapped at any of various angles to attain the desired physical properties. This inner member is then introduced into the outer sleeve, distal end first, until the inner member is completely enveloped by the outer sleeve. An organic matrix material, such as epoxy resin, or a non-organic material, such as liquid glass, is then injected into the space containing the fibers between the inner member and the outer sleeve. A pressurized heat transfer medium is flowed through the inside of the inner member to cure the matrix and to structurally support the inner member to prevent buckling due to matrix injection pressure. Finally, both wall thicknesses are reduced to the appropriate size by chemical etching, to adjust the thermal expansion coefficient of the metal-clad composite to the desired value. Very beneficial results have been obtained by using aluminum tubes to encase a graphite-epoxy resin composite.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a pictorial view showing the insertion of an inner member with attached pre-aligned collimated reinforcing fibers into a surrounding outer sleeve in a process according to the present invention;

FIG. 2 is a pictorial view of an inner member showing the continuous reinforcing fibers aligned in a helical configuration:

FIG. 3 is a cross-section along line A—A of FIG. 1 showing the injection of liquid matrix material into the space between the two members;

FIG. 4 is a pictorial view of the composite structure produced by the process of FIGS. 1, 2 and 3, showing a curing technique for the liquid matrix material;

FIG. 5 is an exposed side view showing an etching method for reducing the wall thicknesses of the outer sleeve and inner member; and

FIG. 6 is a pictorial view of a representative completed metal-clad composite structure according to the present invention.

#### DETAILED DESCRIPTION OF THE INVENTION

As illustrated in FIG. 1 the present invention comprehends using a seamless metallic outer sleeve 10, shown here in its preferred tubular embodiment, with inside dimensions larger than the outside dimensions of a seamless metallic inner member 12. Continuous reinforcing fibers 14, pre-aligned by means such as fiber creel 16 and convergence plate 18, are attached at the distal end of the inner member 12 which is then introduced into one end of the outer sleeve 10 and moved, distal end first, into the outer sleeve 10 until the inner member 12 is completely enveloped by said outer sleeve 10. Beneficial results have been obtained using an aluminum or magnesium clad graphite fiber composite. As shown in FIG. 2, continuous reinforcing fibers 14 may be aligned on inner member 12 in other than a collimated configuration, such as the helical arrangement depicted.

Referring now to FIG. 3, the distal end of the inner space 22 containing the fibers 14 is then sealed and evacuated. Liquid matrix material 20, such as epoxy resin or liquid glass, is injected into the space 22 between the inner member 12 and the outer sleeve 10.

The liquid matrix material 20 is then cured, as illustrated in FIG. 4, by flowing a pressurized heat transfer medium 24, such as hot water or steam in the case of an epoxy matrix, or cold water if liquid glass is being injected, through the inner member 12, forming thereby a fiber reinforced matrix composite material 26.

As shown in FIG. 5, the metal-clad composite structure, denoted generally by 28, is then immersed in a chemical etching chamber 30, wherein the wall thicknesses of both the inner member 12 and the outer sleeve 10 are reduced by processing with a suitable chemical reagent 32, such as sodium hydroxide, to the appropriate

dimension to adjust the thermal expansion coefficient thereof to the desired value.

The completed seamless metal-clad fiber reinforced organic matrix composite structure 28 is shown in FIG. 6 in its preferred embodiment.

It should become obvious to those skilled in the art that this invention is not limited to the preferred embodiments shown and described. In addition to encompassing structures of varying shapes, it is understood that structures of diverse make up are contemplated by the present invention. Very advantageous results have been achieved using an aluminum clad graphite epoxy tube. However, structures of rectangular cross-section and "z-shaped" structures constructed of magnesium and epoxy have also proven very beneficial.

What is claimed is:

1. A process for producing metal seamless clad composite structures comprising:

providing a hollow, metallic inner member;

providing an outer sleeve to surround the inner member and define an inner space therebetween;

attaching to the distal end of the outside diameter of said inner member a plurality of continuous reinforcing fibers;

introducing the inner member, distal end first, into one end of the outer sleeve;

sliding said inner member, distal end first, into the outer sleeve until the inner member is completely enveloped by the outer sleeve;

injecting a liquid matrix material into the space containing the reinforcing fibers between the inner member and the outer sleeve;

flowing a pressurized heat transfer medium through said inner member, to cure said matrix material and to provide structural support; and

reducing the wall thicknesses of both the inner member and the outer sleeve to the appropriate dimensions to adjust the thermal expansion coefficient of the metal-clad composite structure to the desired value.

2. A process according to claim 1 wherein the continuous reinforcing fibers are attached to the inner member by wrapping the continuous reinforcing fibers around the inner member to align the reinforcing fibers in a helical configuration.

3. A process according to claim 1 wherein the continuous reinforcing fibers are attached to the inner member after alignment in a collimated configuration.

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